For publication in ASTM Materials Research and Standards

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Title A New Stress Corrosion Test for Sheet Materials

by

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[1963] 19 p refs Submitted for Publication

19 p.

A new stress corrosion test for the quantitative determination of stress corrosion cracking is described. The method utilizes room temperature compression tests of a small self-stressed sheet specimen. This rapid, simple test permits the early detection of stress corrosion cracking. The method is illustrated by some results of the salt stress corrosion of titanium alloys at 550° F (561°K).

N65 88539	
(ACCESSION NUMBER)	(THRU)
19	None
(PAGES)	(CODE)
TMX 51530	
(NASA CR OR TMX OR AD NUMBER)	(CATEGORY)

FACILITY FORM 602

NASA. Langley Research Center

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A New Stress Corrosion Test for Sheet Materials

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George J. Heimerl and David N. Braski

The susceptibility of various titanium alloy and stainless steel sheet materials to stress corrosion is of considerable concern with regard to their use for a skin material for a supersonic transport operating at speeds up to Mach 3 (1),(2). Such a transport will be exposed to ocean environments and salt on runways, and skin temperatures may extend up to about 600° F (589° K).

Investigations of salt stress corrosion of titanium alloy and stainless steel sheet materials at normal and elevated temperatures are presently underway at the NASA-Langley Research Center and other laboratories. Testing procedures are not standardized and indeed cannot be until more is known about the importance of each of the numerous environmental factors and the basic mechanism involved. Consequently, many different test procedures are being tried.

The need for a large number of small, self-stressed specimens which did not require fixtures, and for a rapid, simple method for the early detection of stress corrosion cracking led to a new type of specimen and test procedure in the NASA investigation (3). This article will describe the new self-stressed sheet specimen and compression test developed in this investigation, and illustrate the method with some results obtained for salt-coated titanium alloy sheet materials exposed up to 10,000 hours at 550° F (561° K).

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Self-Stressed Sheet Specimens.

The construction of the specimen is illustrated in figure 1. Strips four inches long by 1/4 inch wide (approximately 10.16 x .64 cm) are first machined from the sheet (figure 1(a)), and then cleaned and heat treated if such treatment is required to obtain the desired condition. The ends of each strip are then bent to some predetermined angle (figure 1(b)) which depends upon the stress required and must be determined by trial and error. The strips are then cleaned thoroughly (3). In the final step the ends of the two strips are clamped together and spot welded as shown in figure 1(c). This last step produces a constant bending moment on the curved portion of the specimen with equal tensile and compressive stresses in the outer and inner fibers, respectively. Stresses are increased by increasing the bend angle (figure 1(b)). Stresses up to the elastic limit of the material at the exposure temperature may be used. If the stresses exceed this amount, stress relaxation will occur and the initial stress conditions cannot be maintained.

The magnitude of the inner and outer fiber stresses in each strip depends upon the radius of curvature, the thickness, and Young's modulus for the material at the exposure temperature. As long as elastic conditions prevail, the distance d between the inner faces of the strips can be determined for a given maximum fiber stress from the following geometrical and stress-strain relationship:

$$d = 2R - \sqrt{4R^2 - C^2} \qquad (1)$$

where $R = \frac{tE}{2\sigma}$

in which (see figure 1)

[redacted]

R Radius of curvature of curved portion of each strip, in.

C Chord length or distance between bent-up ends, in.

t Strip thickness, in.

E Young's modulus, ksi

σ Tensile or compressive, stress in outer fibers, ksi

Conversely, if the specimen dimensions are given, the stress can be calculated from equation~~s~~ (2) provided the stresses are elastic.

$$\sigma = \frac{2t\,E\,d}{d^2 + C^2} \qquad (2)$$

Specimen Coating and Exposure.

A corroding agent such as salt may be applied to the specimen in various ways by spraying, dipping, or painting with a salt slurry. In the NASA investigation (3) coating was accomplished by dipping the titanium alloy specimens into a boiling, supersaturated solution of pure sodium chloride and drying it in an oven at 250° F. This procedure ~~is~~ was repeated until a uniform salt coating of the desired amount was obtained. Coatings made in this manner can vary from light to heavy. Heavy and medium coatings are uniformly white whereas a light coating consists of a transparent salt film with scattered crystals. Although it was not found necessary to restrict the coating to the curved portion of the titanium alloy specimens, it may be advisable for some materials in order to eliminate the possibility of specimen failure in the sharp bend region near the ends or at the spot welds. To determine the susceptibility of the materials to stress corrosion cracking at elevated temperatures, the coated specimens were placed in an oven at 550° F (561° K) for exposures up to 10,000 hours or more, if required.

Similar uncoated specimens were placed in a separate oven to provide a basis for comparison and data on the stability of the materials after elevated temperature exposure. Specimens ~~are~~ were taken from the ovens after exposure as low as 50 hours for testing at room temperature in order to determine whether stress corrosion cracking had begun. None of the titanium-alloy specimens failed in the oven prior to removal for testing even though stress corrosion cracking had developed, but this may not necessarily be the case for other materials and other test conditions. Most of the specimens were stressed at 100 ksi (689.4 MN/m^{2} *).

Compression Test.

After removal from the oven, the salt coatings are removed by a water rinse and the specimens are tested axially in compression at room temperature as shown in figure 2. The specimen is supported vertically by means of two clamping fixtures. The more elaborate fixture on the bottom, which had previously been used for another purpose, is not actually required; a simpler one such as used on the top of the specimen will suffice provided it adequately holds the specimen perpendicularly to the platen of the testing machine prior to and during loading. The load is applied slowly at a constant arbitrary rate of 200 pounds per minute and recorded autographically against the head displacement or shortening of the specimen. The shortening is measured with a deflectometer consisting of an aluminum-alloy cantilever beam instrumented with strain gages so that their output is proportional to the deflection.

In compression tests of the self stressed specimen, the curvature first increases as the load is applied. With continued loading, the bending tends to concentrate at the ends and middle of the specimen, and when yielding occurs the

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* Mega Newtons/meter^2

specimen legs tend to straighten between these points. The specimen will continue to shorten until ~~either the condition of maximum~~ complete compression and shortening imposed by the fixture (figure 3) or fracture (figure 4) occurs. Fracture ordinarily occurs at the center rather than the ends of the specimen in the compression tests.

Characteristic configurations of the uncoated specimens and the coated specimens of Ti-8Al-1Mo-1V ~~specimens which had~~ containing stress corrosion cracks are shown before and after testing in figure 5. The marked change in configuration, bend ductility, and shortening caused by stress corrosion cracking demonstrates the sensitivity of the compression test to this type of corrosion.

<u>Effect of Stress Corrosion Cracking on Shortening.</u>

The change in specimen shortening or bend ductility, obtained in the room temperature compression test, is a measure of the amount of stress corrosion cracking which has occurred. Illustrative results for a titanium alloy stressed at 100 ksi (689.4 MN/m^2) with a heavy salt coating after exposures up to 10,000 hours at 550° F (561° R) are shown in figure 6. A single dashed load-shortening curve (figure 6(a)) which represents all of the tests of the uncoated specimens, shows that there was no effect of exposure on the strength or bend ductility; all of the specimens reached the maximum shortening condition without fracture. The solid curves represent the tests ~~for~~ at each exposure time in which the most severe stress corrosion cracking occurred. These curves ~~are all~~ essentially ~~the same~~ coincide up to the point where a sudden drop in load and fracture occur. The shortening at fracture decreases in a regular fashion with increasing exposure time, indicating a greater severity of stress corrosion cracking at the longer times.

The shortening measurements for the individual tests for this same material are shown in figure 6(b). The dashed line for the uncoated specimens again shows no effect of exposure time. The solid line or limiting curve represents the most severe stress corrosion effects obtained in the tests. Considerable scatter can be noted in the results but this is characteristic of corrosion tests. No definite trend can be established as far as the longitudinal and transverse directions of the material are concerned. In this instance severe stress corrosion cracking occurred within 4,000 hours.

Crack Penetration and Correlation with Shortening Measurements.

In order to determine the nature and extent of the stress corrosion cracking and verify the results of the compression tests, metallographic examinations were made of the cracks generated at ~~emanating from~~ the surface of the specimen. The depth of the crack penetration was measured with a light microscope and micrometer eyepiece. Crack measurements were made on untested as well as tested specimens; in each case small pieces were cut from each curved strip or leg of the specimen for examination and measurement of the cracks. In the case of the tested specimens, measurements were made some distance from the point of fracture or maximum bending; there was no indication that the crack depth away from the fracture point was influenced by the bending of the specimen in the compression test. When the specimens were badly corroded, cracks were numerous and distributed along the length of the specimen in a direction normal to the induced stress. A typical edgeview of an intergranular corrosion crack in a titanium alloy stressed at 100 ksi (689.4 MN/m^2) and exposed for 2,000 hours at 550° F (561° K) is shown in figure 7.

Illustrative results of the crack penetration measurements for a titanium alloy with a heavy salt coating after exposure at 550° F (561° K) with a stress of 100 ksi (689.4 MN/m^2) are shown in figure 8. The number and range of the measurements are indicated for various exposure times. As in the case of the shortening measurements a considerable amount of scatter of the data was obtained. The limiting curve represents approximately the maximum amount of stress corrosion crack penetration. The ~~buckling~~ levelling off of both the maximum crack penetration curve (figure 8) and the minimum shortening curve (figure 6(b)) may be due in part to the reduction in the applied bending stress at the crack tip as the ~~material~~ neutral axis is approached and perhaps partly to the ineffectiveness of the solid surface salt in penetrating to the bottom of the crack.

The correlation of the minimum shortening curve (figure 6(b)) with the maximum crack penetration curve (figure 8) on a time basis for Ti-6Al-4V titanium alloy sheet is shown in figure 9. The decrease in shortening corresponds directly to the increase in crack penetration for various exposure times at 550° F (561° K). Consequently, the shortening measurements obtained in the compression test are evidently a good measure of the amount of stress corrosion damage which has occurred. The relative susceptibility of various materials to stress corrosion cracking can ~~likewise~~ be determined by this method (3).

Concluding Remarks.

The new method described herein for determining the quantitative effects of stress corrosion cracking in sheet materials has a number of advantages. The self-stressed specimen is small, easily constructed, and does not require a fixture. Space requirements are a minimum. The amount of stress corrosion damage can be easily and quickly ascertained at any time from the simple room temperature compression test so that it is possible to detect stress corrosion cracking long before specimen failure would otherwise occur. Shortening measurements obtained in the compression test correlate well with crack penetration measurements, and time consuming metallurgical examinations of each specimen are not required to assess the extent of the cracking. The compression test provides quantitative data on the reduction in shortening, bend ductility, and embrittlement due to stress corrosion cracking. As in the case of other stress corrosion tasks involving bend type specimens, this new test does not provide any quantitative information on the effect of stress corrosion cracking on the tensile properties.

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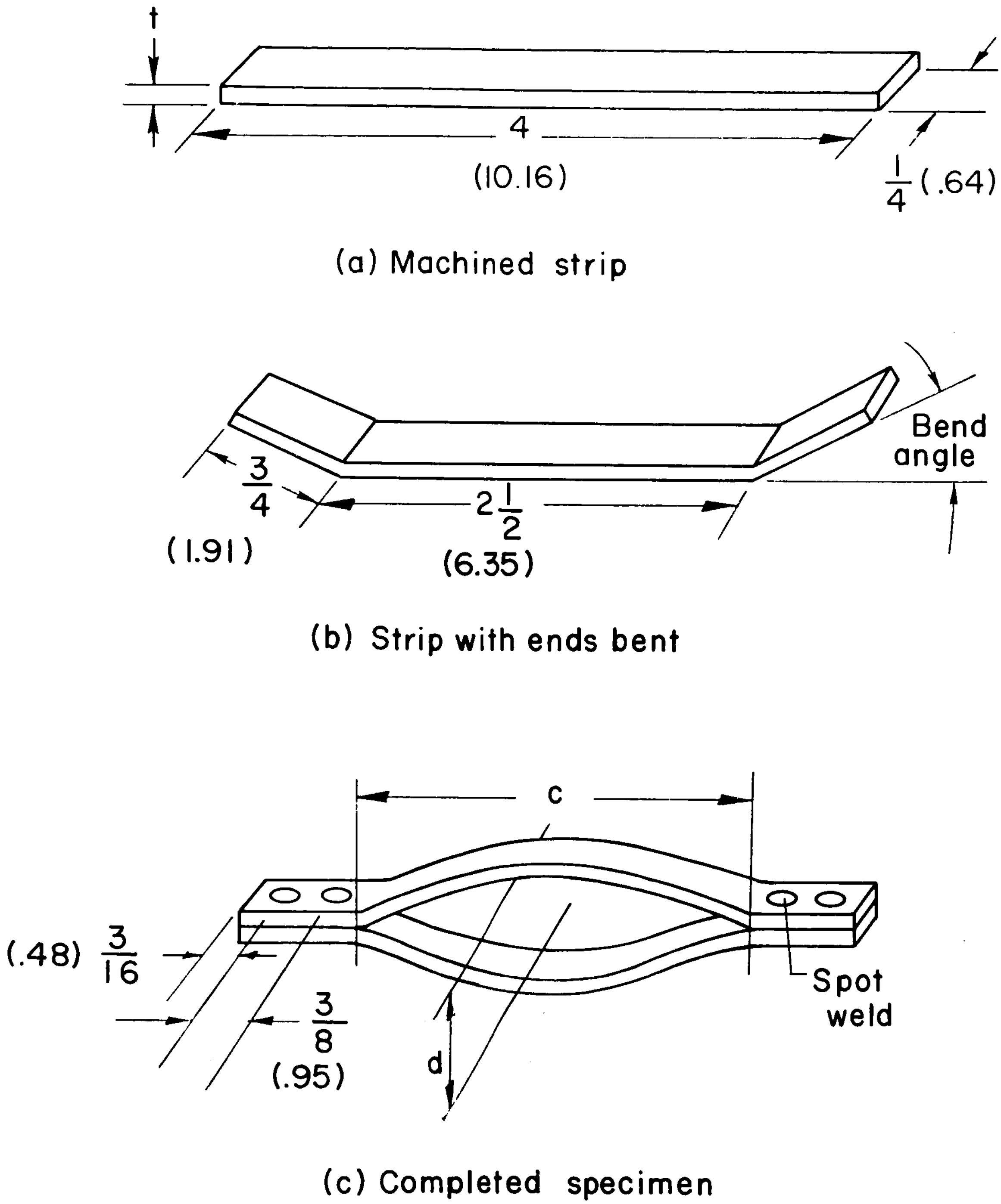

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Figure 1.- Construction of the self-stressed specimen. Dimensions are given in inches and parenthetically in centimeters.

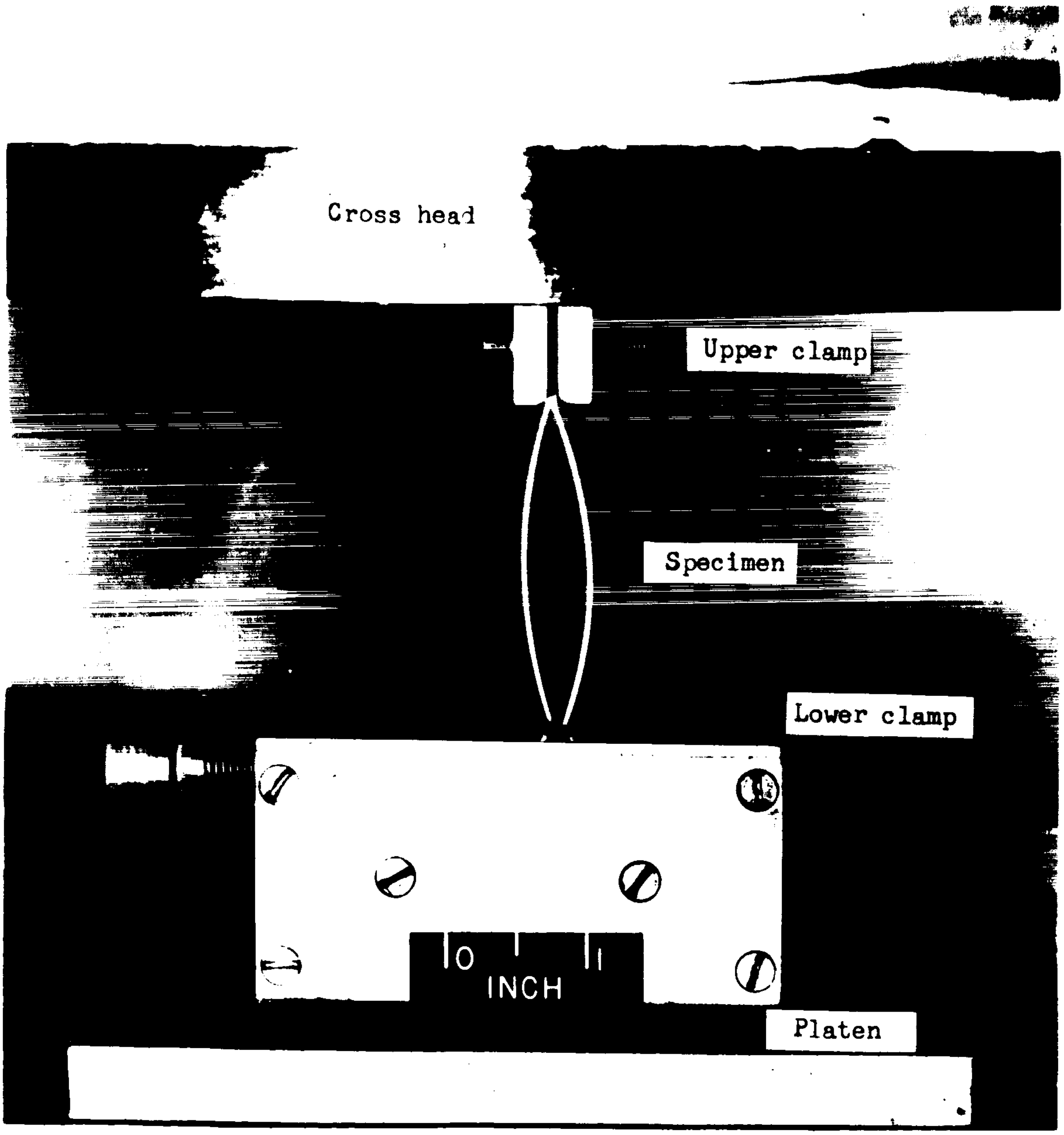


Figure – 2 – Clamping fixtures and compression test apparatus.

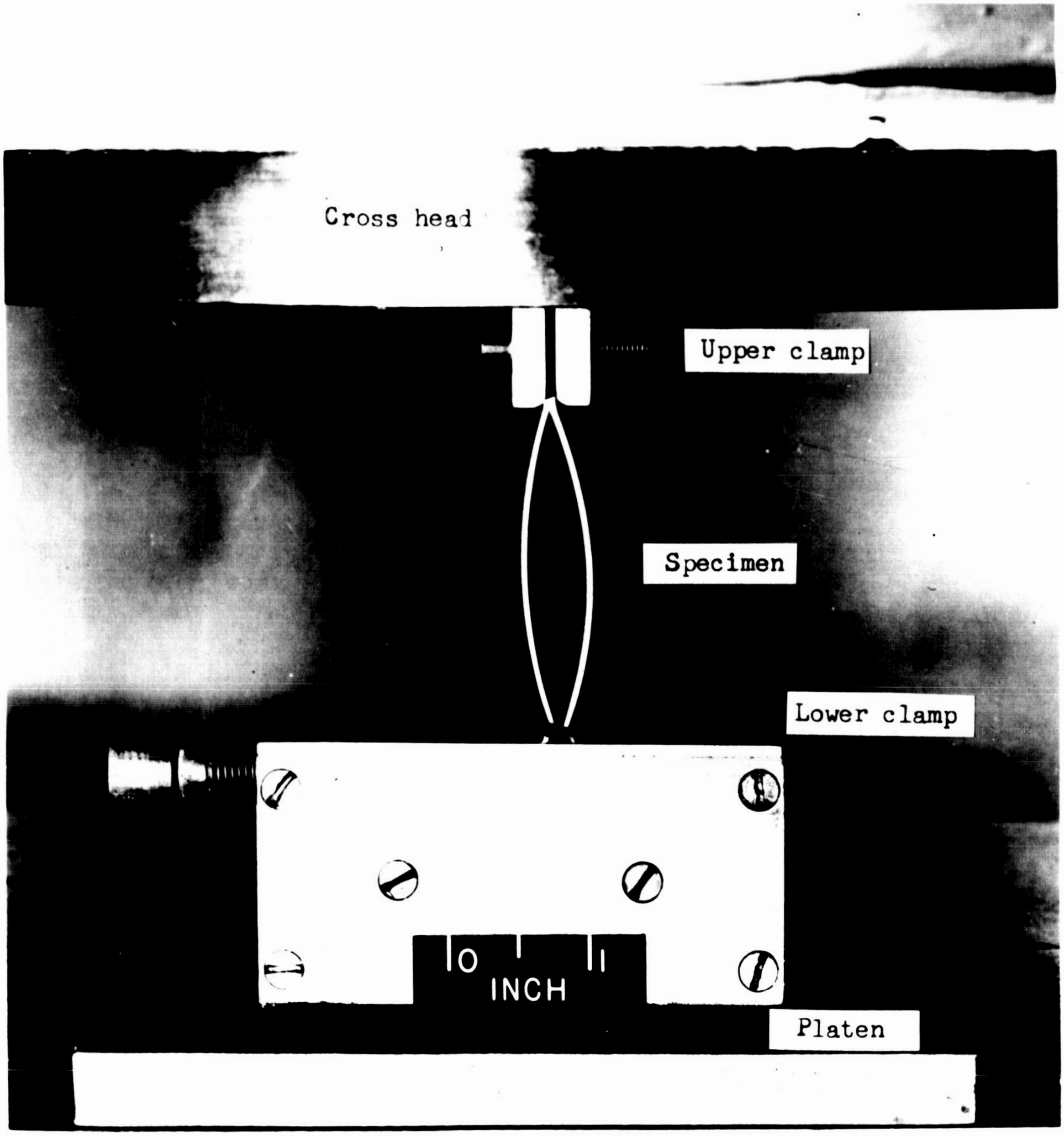


Figure – 2 – Clamping fixtures and compression test apparatus.

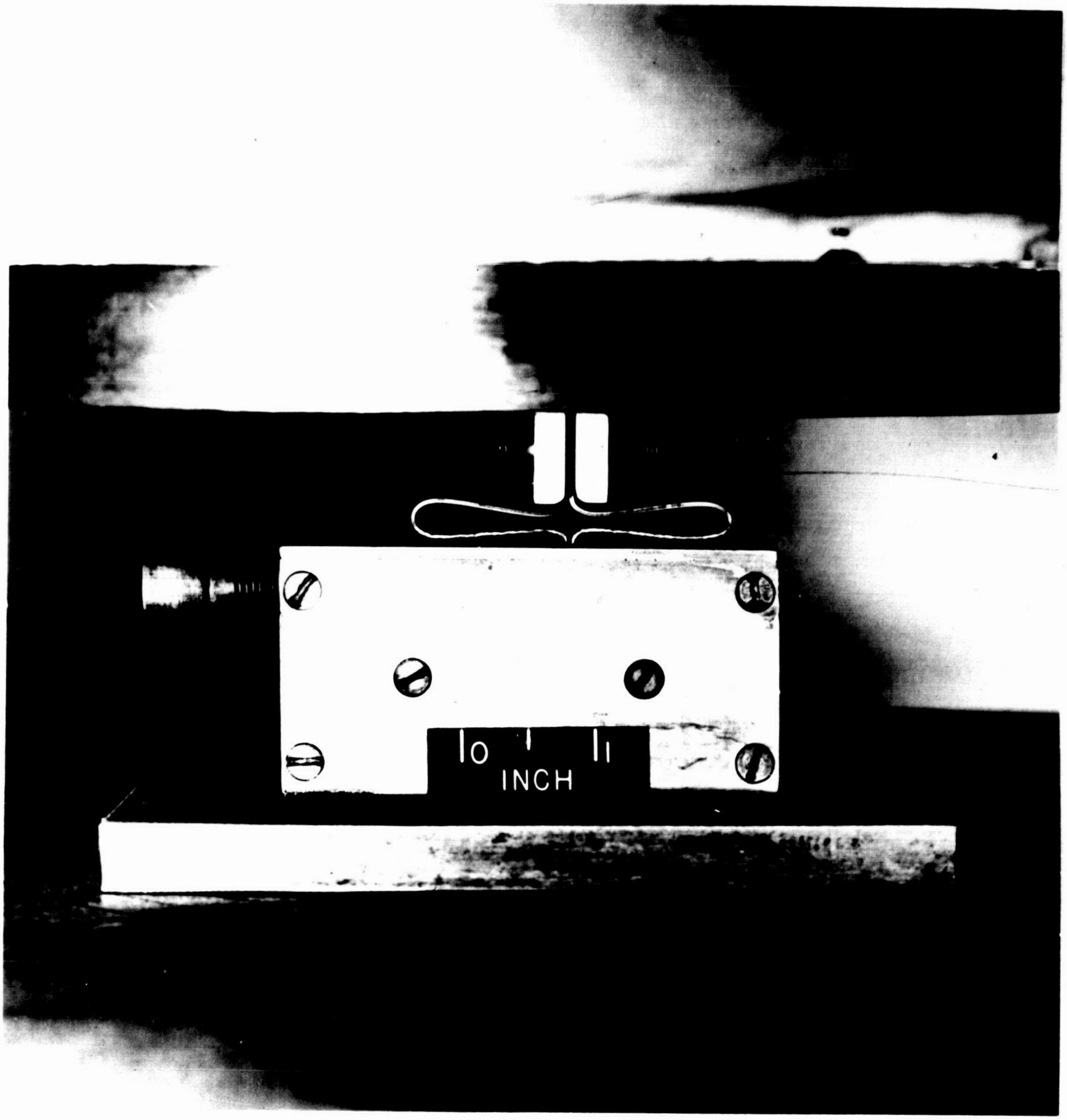
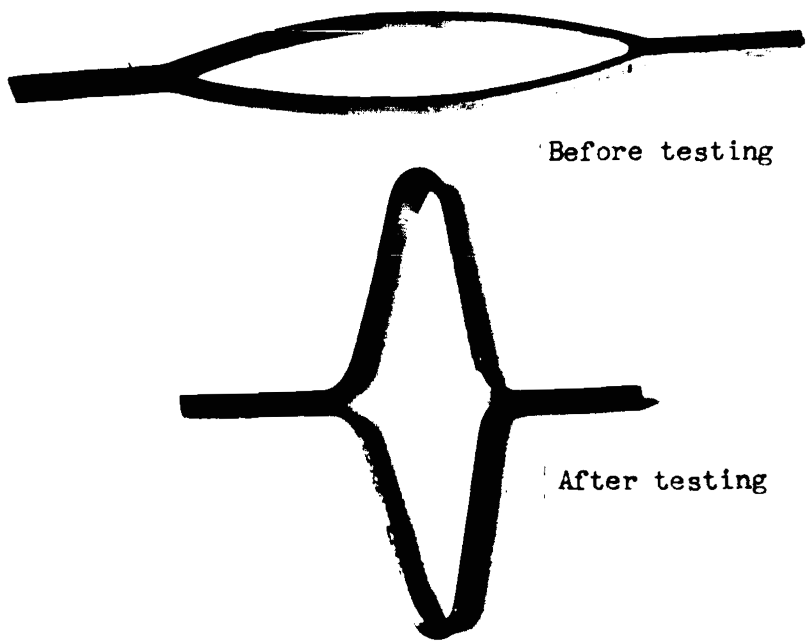
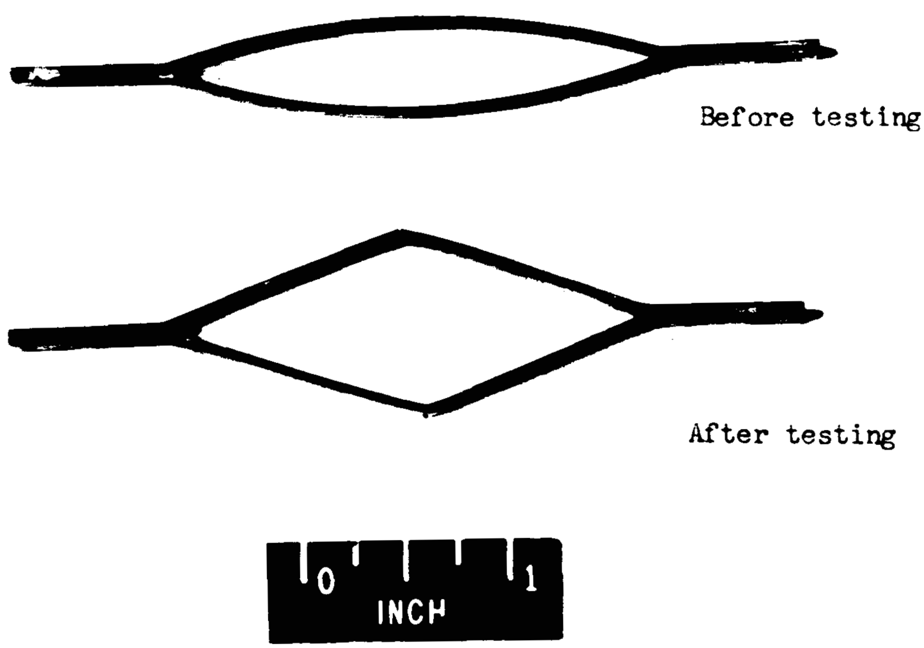


Figure – 3 – Uncoated specimen at condition of "maximum shortening" without failure.



(a) Uncoated



(b) Salt coated

Figure 5 – Specimen configuration of uncoated and salt coated Ti–8Al–1Mo–1V specimens stressed at 100 ksi(689.4 MN/m^2), before and after compression testing at room temperature. The specimens were exposed at 550°F(561°K) for 2000 hours prior to testing.

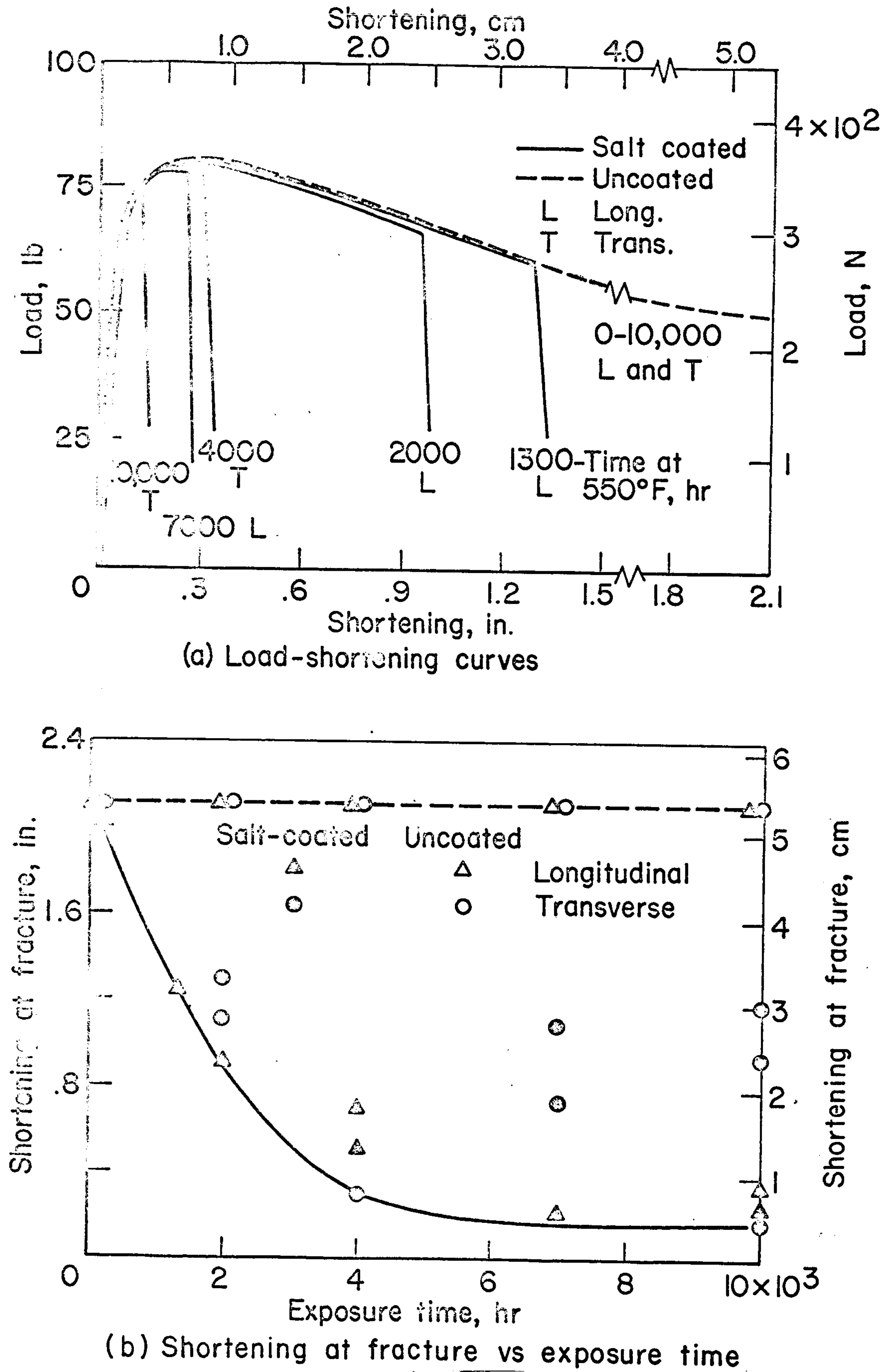


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Figure 6.- Results of the compression tests for the Ti-6Al-4V specimens stressed at 100 ksi (689.4 MN/m^2).

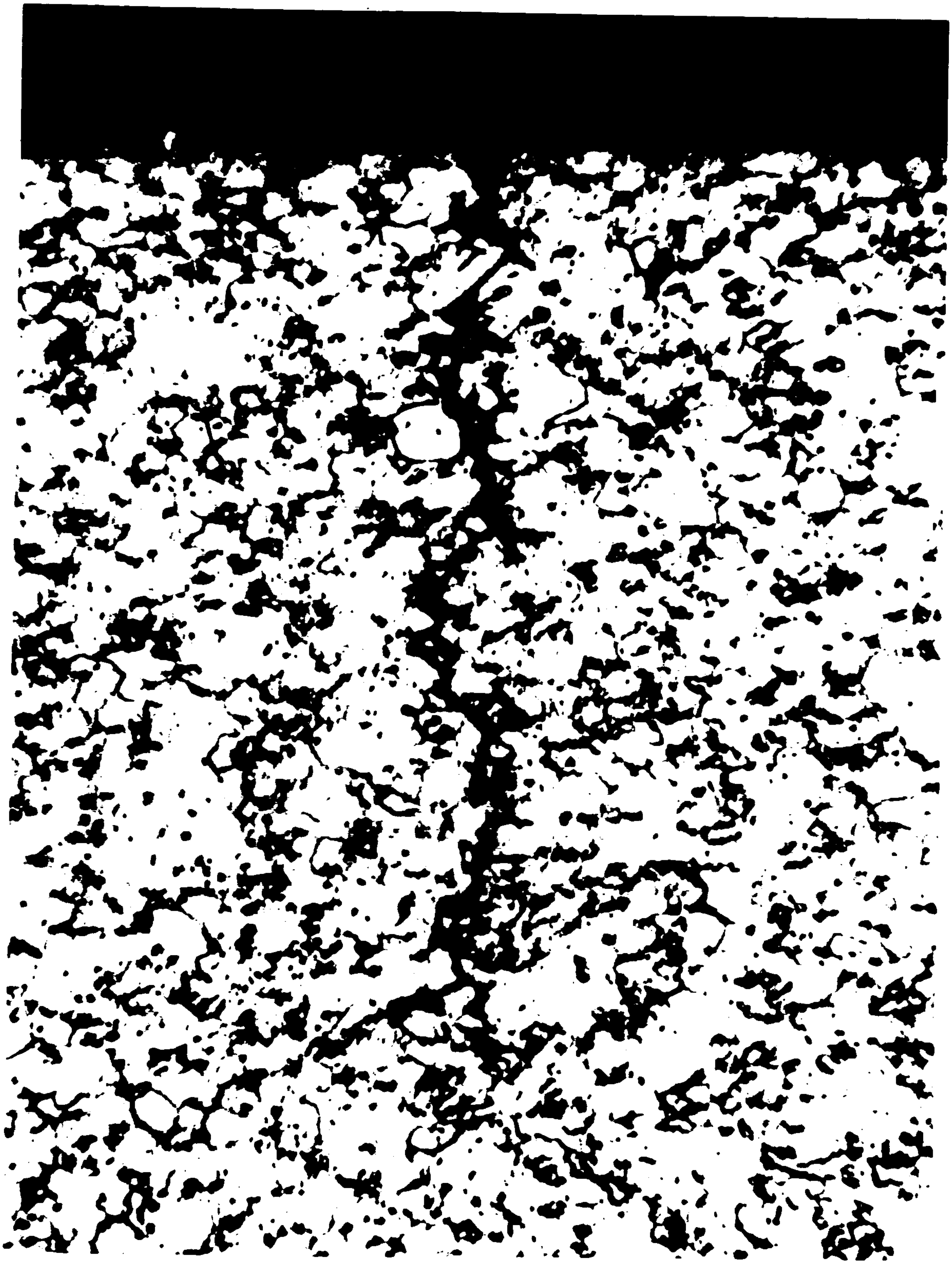

Figure – 7 – Edge view of stress corrosion crack in Ti–8Al–1Mo–1V
longitudinal specimen exposed 2000 hours at 550°F.

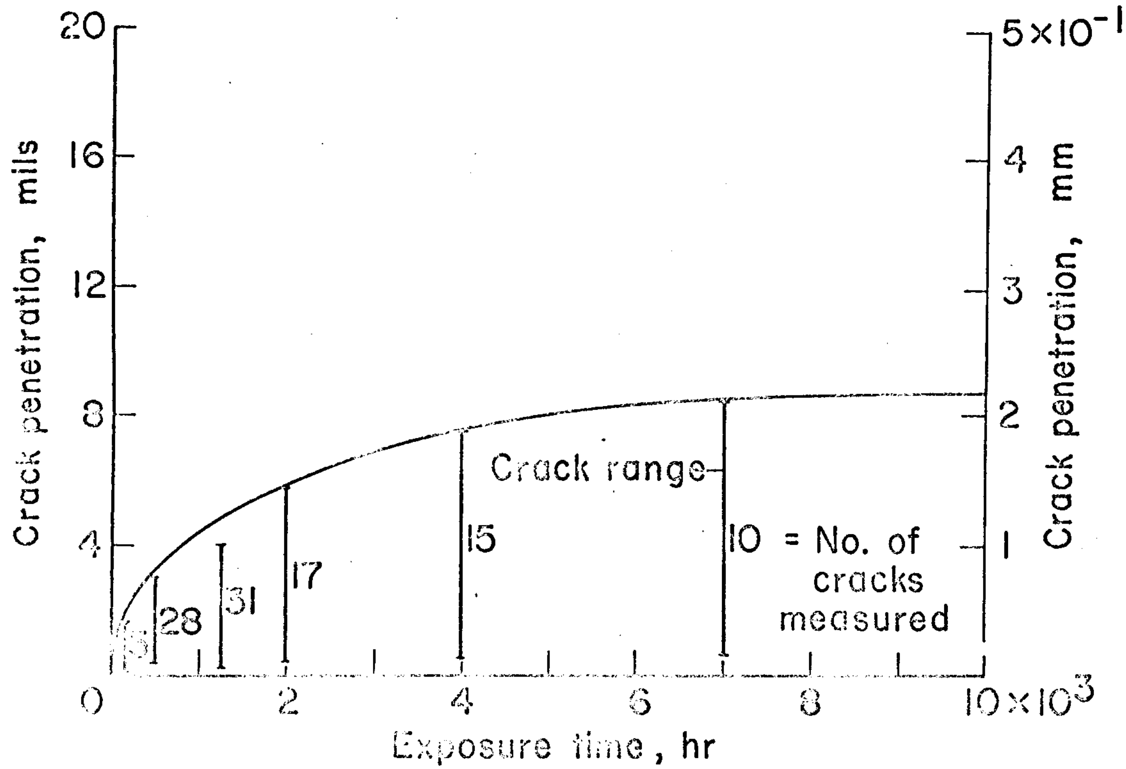

Figure 8.- Crack penetration in Ti-6Al-4V exposed at 550° F (561° K) with a stress of 100 ksi (689.4 MN/m^2).

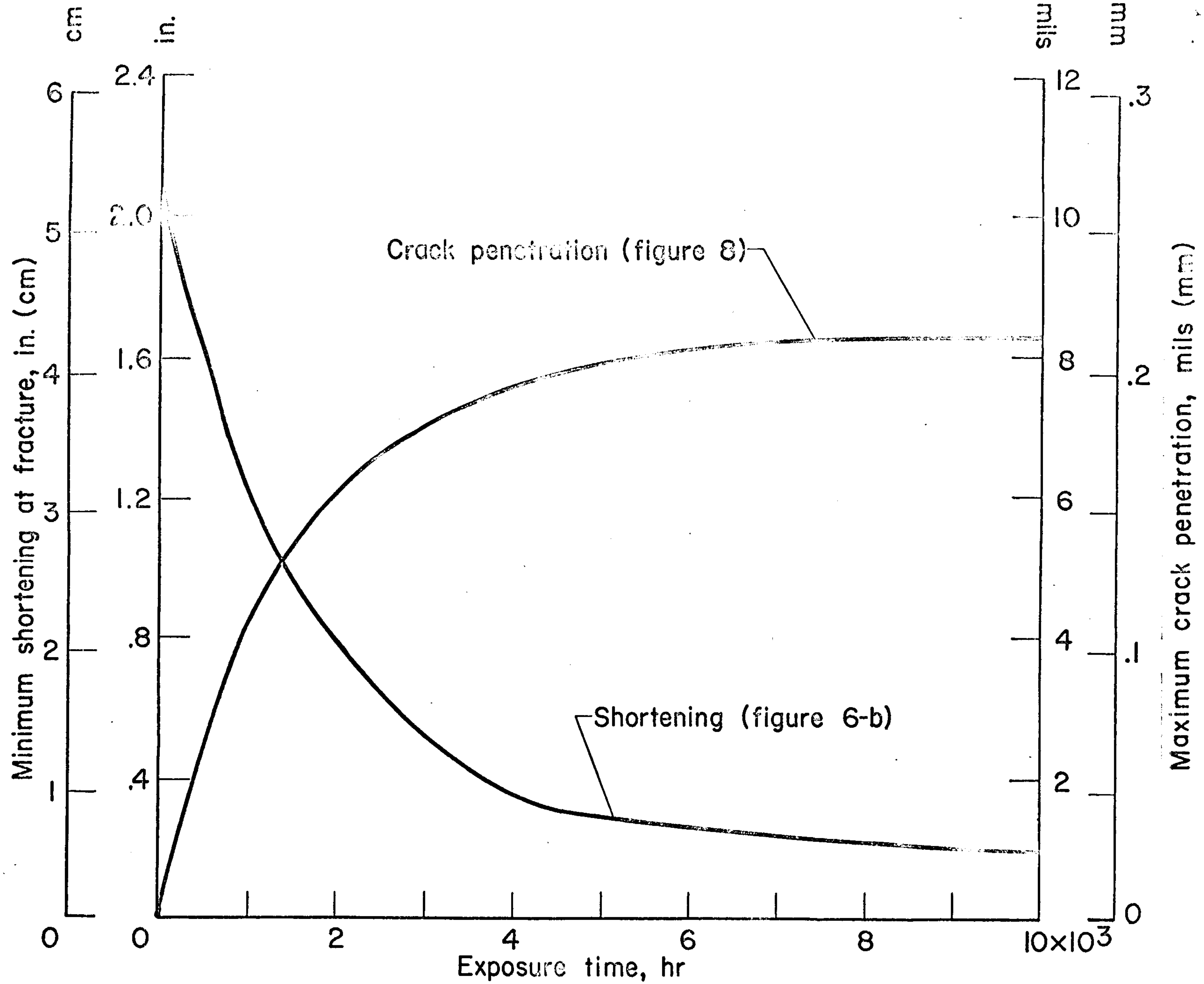

Figure 9.- Correlation of minimum shortening with maximum crack penetration for Ti-6Al-4V specimens after exposure at 550° F (561° K).